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THE TUBERCULOSIS LEAGUE, THE SANATORIUM, AND INDUSTRY*

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THE past decade has seen a striking development in the extension of industrial hygiene by tuberculosis associations in the United States. This has been brought about by various factors among which may be mentioned briefly the following: (1) general recognition that tuberculosis is an industrial problem and that industrial health is a tuberculosis problem; (2) surveys showing the general lack of medical supervision in the majority of industrial establishments; (3) studies on the staggering economic loss due to tuberculosis, one of the "silent sicknesses;" (4) comparative studies of the decline of the tuberculosis mortality rates in the working age groups and in other age groups; and (5) the tremendous problem of placing patients discharged from the sanatorium in suitable and gainful employment.

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Tuberculosis is basically a problem of the working man and woman, since one out of every three or four deaths between the ages of 15 and 45 years occurs from tuberculosis, and the peak of our death rate is in the period of our greatest productivity. Since the tuberculosis campaign has been largely one of education, the tuberculosis associations can reach this large group of tuberculous adults in the industries, for here we have some 40,000,000 people in groups of various sizes who are much more easily approached than they would be as individuals.

Industrial activity is a factor in the development of many cases of tuberculosis, and industry is concerned with the recognition and treatment of the disease, but as Wade Wright has pointed out, the great majority of cases cannot be attributed directly to the effects of work at particular jobs. He asks for a differentiation between

tuberculosis in industry and industrial tuberculosis. The two are vastly different. That there are many cases of tuberculosis in the industrial wage earning age groups no one will gainsay, and it is to this group that attention should be directed.

As recently as 1922 the Philadelphia Health Council and Tuberculosis Committee following Dr. Horwood's tuberculosis survey of Philadelphia, instituted its industrial service which is now being used as a plan in embryo for other tuberculosis associations to follow. The realization of the importance of including such a service in a well-rounded tuberculosis program was inspired by Dr. Horwood when he recommended that special emphasis be directed toward finding the early adult cases of tuberculosis, especially among those in industry; in order to achieve this end he suggested an invasion of industry by the introduction of the antituberculosis campaign, "through the holding of clinics, the use of tuberculosis nurses, and the dissemination of knowledge concerning tuberculosis." That Dr. Horwood's recommendations have been inspirational is evidenced by the fact that the Philadelphia Plan has been adopted in several other communities with varying degrees of success. The development has been progressive though slow.

Drolet, in 1922, in discussing the extension of tuberculosis dispensary work into industry wrote: "Tuberculosis work, addressed as it is primarily to the home and especially to the protection of childhood, has been steadily and progressively protective; but the wage earner and industry have been practically untouched." Progress is now being made, even though it is slow. The extension of industrial medical practice will assist materially in speeding up tuberculosis work, but only when the smaller plants are reached, for the majority of the 40,000,000 industrial employees in the United States are employed in plants of less than 500 workers, constituting 99 per cent. of the industrial establishments and employing more than 60 per cent. of all the wage earners. If industrial medical supervision is to be successful in the country at large, it must be made available to this vast majority of plants.

The surveys of industrial medical facilities in the plants of Philadelphia, New York City, Paterson, Newark, Hudson County, and other districts show a general lack of industrial medical supervision in the larger plants and even less service for employees in the remaining plants especially in those which have from twenty-five to 100 employees. In Hudson County, which has a total population of 725,000, there is an industrial population of 112,000 men and women in its 2,350 industrial establishments. A preliminary survey showed that only 14.9 per cent. of them had any sort of medical service and the majority of those had only a physician on call.

The industrial health service of the Hudson County Tuberculosis League was begun in February, 1928. Employers were interviewed; noonday talks were given in industrial establishments; posters, leaflets, and pamphlets on health matters were distributed; motion pictures were shown and health examination clinics set up in the various plants. In the talks the value of the health examination was stressed; it was pointed out

that the examination would be confidential between the examining physician and the employee, that the examination was not compulsory, and that there would be male physicians for the men and female physicians for the women. A heartier response than had been anticipated greeted the introduction of the work, approximately 80 per cent. of the employees reached voluntarily submitting to the examination.

After the employers and employees consented to the examinations, the clinic was established in some convenient place in the plant. In the clinic an industrial nurse assists the physicians, takes the histories of the examinees, and carries out the follow-up program. The employee is given a complete physical examination stripped to the waist. He is questioned concerning past illnesses, particularly of the respiratory type, and as complete a family history as possible is taken. A specimen of urine is required of each examinee.

Analyzing the results of the examinations we found that the defective conditions detected among these apparently healthy men and women were in accordance with results obtained in other physical examination services, dental defects standing out most prominently. Cases of malnutrition, underweight and overweight, and tendency to hypertension accounted for approximately 25 per cent. of the defects. In 1,099 examinations, 123 chest cases were detected, of which 54 were diagnosed as observation cases and 3 as positive cases, and referred to their family physicians and tuberculosis clinics for further examination and treatment. These figures are considerably lower than those found in our experience in Newark where, in the course of 3,500 examinations, we found 80 positive and observation cases of tuberculosis, of which 60 were later definitely diagnosed as tuberculous and 39 were sent to sanatoriums, later to be discharged as arrested cases and returned to their former employment.

The results of the examinations showed further that 10.6 per cent. were free from physical defects, 54.8 per cent. were found to have minor defects, 26.3 per cent. had advanced minor defects, and 8.3 per cent. had major or numerous advanced minor defects. (See Table 1.)

TABLE 1.—GENERAL CLASSIFICATION OF DEFECTIVE CONDITIONS

CLASS	NUMBER	PER CENT.
A. No defects	116	10.6
B. Minor defects	602	54.8
C. Advanced minor defects	289	26.3
D. Major defects	92	8.3
Totals	1,099	100.0

As is usual in examinations among large groups of men and women, a great number of defective conditions of teeth, diseased tonsils, visual defects, high blood pressure, and faulty nutrition were found. A specific classification of defects requiring correction is given in Table 2.

The service provides for an individual report which is sent to the employee at his home, and for a general report to the employer appraising him of the number of employees examined, the general classification of cases according to their health, and a

TABLE 2.—SPECIFIC CLASSIFICATION OF DEFECTS REQUIRING CORRECTION

CONDITION	NUMBER	PER CENT.
Defective teeth and gums	490	44.5
Underweight	257	23.3
High blood pressure	250	22.7
Defective tonsils	228	20.7
Ears (defective hearing and cerumen)	191	17.3
Constipation	168	15.2
Visual defects	158	14.3
Overweight	146	13.2
Chest defects	123	11.1
Anemia	116	10.5
Heart defects	74	6.7
Thyroid enlargements	45	4.0
Nasal defects	55	5.0
Wassermann tests indicated	55	5.0
Dysmenorrhea	53	4.8
Defective feet	48	4.3
Hemorrhoids	41	3.7
Hernia	36	3.3
Skin defects	33	3.0
Varicosities	30	2.7
Poor posture	30	2.7
Urine:		
Sugar	1	0.1
Albumin	17	1.5
Vaccination advised	13	1.1
Nervous disorders	11	1.0
Tumors	11	1.0
Gastro-intestinal disorders	8	0.7
Deformities	5	0.4
Sinusitis	4	0.3

statement of the defects found, the defects in some instances being classified according to the departments in which the employees are working. Also, a sanitary survey is made and reported on.

Of great importance in the industrial health work of the League is the follow-up work conducted by the industrial nurse in co-operation with the tuberculosis clinics in tuberculous cases, with the various social service agencies, and with the private family physicians. Every case requiring attention is followed up by the nurse who gets in touch with the employee's private physician when necessary, or with the proper clinic and social service agency when this procedure is deemed expedient. Whenever the examiner's report indicates the necessity of immediate attention, the employee is immediately referred to his private physician or to the proper clinic. In the first year of the service in Hudson County, 932 examinees were referred to physicians, dentists, and clinics. Of those referred to their physicians, our follow-up records show that 61 per cent. have followed the advice of our examiners and have visited their doctors. In the 123 chest cases referred for further examination, the extent to which the examinees are co-operating is shown in the following tabulation:

	Number
Have had further examinations	73
Attending clinics—observation cases	13
Attended clinics—reported negative	12
Examined by family physician and are under his care	44
Refused follow-up interview	5
Moved out of county	5

The examinations and follow-up have also resulted in the following: Eight persons have had their tonsils removed, fourteen are wearing glasses to correct faulty vision, one patient was hospitalized for a period of one month with acute nephritis, one hemorrhoidectomy was performed, nine persons are wearing trusses for hernia, and eight are wearing arch

supports. An increasing number are visiting their dentists for the correction of dental defects.

Concerning the follow-up of tuberculous cases, we are most fortunate in having recourse to the Hudson County Tuberculosis Clinics which are open every day and one evening a week. The clinics co-operate beautifully in the further examination, including X-ray, of the observation cases. The importance of the evening clinic cannot be overemphasized, for the employee is thereby enabled to have his reexamination without losing time from his work. We are further fortunate in having a State Board of Children's Guardians Fund by which the family may be cared for should the breadwinner of the family be required to go to the sanatorium. Also, for those cases requiring immediate hospitalization pending their admission to the sanatorium, there are beds available at the Jersey City Hospital. These beds are inadequate in number to meet the demands, but they assist tremendously.

When it is felt that the demonstration of the value of industrial medical supervision has fulfilled its purpose, an attempt will be made to have industry take over the work according to the practicable plan outlined by Dr. Harvey Dee Brown of Philadelphia. The plan in brief is this: Units consisting of a group of plants which have from 100 to 500 employees each and are reasonably near each other, providing a total of 1,000 employees, are established. Each plant sharing in the unit service is required to provide a first aid or clinic room in the plant, properly equipped, and to pay monthly its pro rata share in the cost of the unit based on the average number of employees. The Health Council organizes the service and supervises the preparation of suitable rooms for clinics with necessary equipment and supplies which are purchased for the plant. It also administers the service for a temporary period and furnishes the necessary blanks.

The Unit Plan has for its object the following:

1. Physical examinations of all employees, including preemployment examinations, and reexaminations at stated intervals of employees having physical defects.

2. Medical and surgical relief, including emergency treatment of accidents and minor illnesses occurring at the plant and follow-up of compensable cases, advice as to the correction of defects found on examination, follow-up of such employees in homes when necessary, and co-operation with the family physician of the sick, injured, or defective employee.

3. Instruction in first aid to sick and injured to a selected group in each plant so that there will be some one to give first aid in case of accidents when the physician or the nurse is not at a given plant.

4. Industrial hygiene and sanitation including sanitary survey of plant annually and sanitary supervision with monthly inspections of the plant.

5. Health education and hygienic instruction including health talks to employees, health classes for women workers, a monthly poster service, and motion pictures on health problems affecting industrial workers where suitable arrangements can be made.

According to Dr. Brown, "from the point of view of the employers' inter-

est, such a service would decrease absenteeism and labor turnover with consequent increase of production and decreased cost. This would be brought about by the prevention of contagious diseases through their detection and isolation, the prevention of slight illnesses developing into serious sicknesses, the diagnosis of early beginnings of serious types of illnesses, as for example tuberculosis, kidney disease and heart disease; advice to employers in placing physically defective workmen at occupations where they could do efficient work and information regarding sanitation, and any industrial health problems which might arise. The plan of operation of the service was that regular daily or semi-weekly visits to each plant would be made by physician and nurse according to a definite schedule providing for a given amount of time to each plant determined by the number of employees. A minimum of 3 hours per week of health work for each 100 employees was to be provided. In addition to the scheduled visits special visits for redressings, examinations, etc., would be given as needed."

Philadelphia has been successful in transferring two established units to industrial plants, the physician and nurse who had been doing the work going with the unit and becoming the employees of the plants with fixed schedules and definite salaries from each plant in proportion to the time given.

It is important indeed to find cases of tuberculosis and to discover them early, but it is also very important to provide for them when they are discharged from the sanatorium as arrested cases. To this end the Hudson County Tuberculosis League has established a placement bureau, for which there is a definite need. Although the bureau has been operating but a short time, fifteen discharged patients have applied for placement, seven of whom have been referred to positions. Questioning many employers has shown that in several instances industry is willing to accept the discharged sanatorium patient if:

1. The patient has left the sanatorium with the advice and consent of the medical director.

2. The sputum is negative.

3. The work capacity of the patient has been determined.

4. The patient is capable of doing the work.

If the patient is a former employee of the plant, his position is ready for him upon discharge, but if he should apply elsewhere a waiting period is generally insisted upon. In one of the largest plants in the county a waiting period of one year is demanded. This works a hardship on the patient and if the maximum benefit is to be derived from sanatorium treatment we must prepare him for the change from the curriculum of rest at the sanatorium to his new curriculum. How best shall we prepare him for the new activity?

At least three months before a patient's discharge from the sanatorium he should be given graduated employment or work of some kind, preferably with pay, around the sanatorium. His condition should be carefully watched as he adapts himself to his new status. The industry in which he was employed before he came to the sanatorium should be

notified of his progress and particularly to the effect that discharge may be looked for at a certain date. This will enable the employer to make suitable arrangements for the acceptance of his former employee. In the event that there is no position available, a similar procedure should be carried out with the local tuberculosis league, or with a public employment bureau. The sanatorium or clinic or tuberculosis league should have on its staff a social worker or nurse who understands this important phase of rehabilitation work. In southern Minnesota eight counties are now benefiting from a rehabilitation service started by the Minnesota Public Health Association. According to Mr. Rosell of this association, in addition to providing protection for the former sanatorium patient, the service will also afford an economic saving to the community. He says:

> County funds are wasted when a tuberculous patient, after money has been expended in an effort to preserve his life for his family and community by sanatorium care, obtains an unsuitable job which may bring on a relapse. In addition to giving the patient repeated sanatorium care, it generally is necessary for the county to take care of the family. By obtaining suitable positions for former tuberculous patients and by checking their health periodically, the new service will prevent relapses, thus guarding interests of the employer, economizing on community funds and protecting the arrested tuberculous case.

We appreciate fully that it is most difficult at times to procure employment for the nontuberculous, particularly in times of excessive unemployment, but we should make every effort to place the discharged patient in work for which he is adapted and which he is capable of performing.

The splendid report of Dr. F. N. Kay Menzies on the "Employment of Tuberculosis Patients" bears the following conclusions which are worthy of consideration:

1. The problem of the unemployed person suffering from tuberculosis is in many respects similar to that of the unemployed healthy person.
2. A reduction in the total number of unemployed will be associated with a fall in the number of tuberculous unemployed.
3. Speaking generally, the working capacity of the tuberculous person whose disease is not arrested is not more than 50% of the normal person.
4. Many of these partly incapacitated persons, though unfit for work as ordinarily carried out, are capable of being employed to a varying extent under special conditions.
5. These special conditions include various forms of employment which call for little physical effort together with hours of work regulated to the physical capacity of the employee and a hygienic environment.
6. The loss of efficiency of the tuberculous worker can be made good to some extent by the use of labour-saving methods.
7. Wherever possible, a tuberculous person should seek for an employment for which his previous experience fits him. The best course as a rule is the return, perhaps under modified conditions, to his usual employment.
8. Experience has shown that the training of adults over the age of 25 in a new occupation, regarded as suitable on medical grounds, is not practicable as a general policy. The training of ex-service pensioners has proved to be of very little value.
9. The training of tuberculous persons at the younger ages would probably prove more satisfactory, but as yet, in respect of pulmonary cases, there is little experience upon which to base a definite opinion.
10. In some cities the employment of a limited number of tuberculous persons by public bodies, *e.g.*, in parks, has been found practicable. Institutions for the treat-

ment of the tuberculous also have absorbed a certain number of patients as members of the staff. Difficulty, however, commonly arises on the question of superannuation and pension.

11. Care Committees and similar voluntary agencies have succeeded to a limited extent in placing tuberculous patients in suitable occupations, and under present conditions they can do more for patients than any other agency. Care Committees do not attempt to create employment but aim at securing vacant situations for their clients.

12. In some areas, a few patients have been found employment in unskilled occupations, such as jobbing gardeners, basket-work, car-park attendants, etc. Sanatorium superintendents can co-operate in this direction by giving patients, as a part of their treatment, instruction in simple handicrafts, etc.

Whether the "Care Committee" emanates from the sanatorium, clinic, or tuberculosis association makes little difference as long as there is some person or group to whom is intrusted the follow-up of these patients from the standpoint of providing employment.

The Standard Oil Company of California in its experiment in the care of tuberculous employees established the Standard Oil Company Sanatorium with two objects in view: namely, to restore to work persons having favorable prognosis, and to furnish care and treatment for life to those with hopeless cases. Regulations to promote these ends were to the effect that every tuberculous employee be offered treatment; that all patients be under the full control of the medical superintendent; that no patient be discharged until fit for light work; and finally that the medical superintendent prescribe for each discharged patient the type of work and the number of hours he shall work. The treatment is the same as that given in all well-conducted modern sanatoriums, except that upon discharge the two latter regulations obtain. In my opinion the sanatorium renders a valuable service to the individual and to the community by making an appraisal of the individual's work capacity and informing him and certifying him concerning the amount of work he should perform, according to the best judgment of the examining physician.

The Union County Tuberculosis League in New Jersey conducts chest clinics in industrial plants, but the work is done by physicians connected with the County Sanatorium. This is a departure from the program in Philadelphia and the three communities in New Jersey where the examinations are made by physicians engaged by the tuberculosis league. The Union County demonstration is primarily interested in discovering cases of tuberculosis, whereas the others are attempting to demonstrate the value of a complete system of industrial medical supervision. Both have their place in the tuberculosis program inasmuch as they are case finding mediums.

The tuberculosis sanatorium and clinics, in order to render the greatest service to the community, may well consider the establishment of consultation clinics in industrial establishments having 1,000 employees and over. The clinic should be held once a month, at which time special cases referred by the medical department may be examined on company time. If facilities for this diagnostic and consultation service are provided, a splendid medium for finding tuberculous cases

will result. Firms and corporations through their medical departments may use this service particularly for employees who may be missing work on account of illness and who may thus be checked up for the reactivation of latent tuberculosis.

The experience of the Westinghouse Electric and Manufacturing Company of Pittsburgh in the matter of the care of the tuberculous is interesting. When a case of tuberculosis is discovered among their workers immediate steps are taken to have the patient admitted to either a state or a private institution. At the same time the other workers that are in close contact are examined; and the patient's family, in case he is married, is also brought in for examination. In several instances the children have also been sent away for treatment. When the employee is able to work again he is given suitable work and reexamined once every month for a period of six months, and later every six months, in order to see if he is holding up under the work in which he is engaged. Occasional letters are written to all superintendents and foremen calling their attention to the importance of finding tuberculous cases early in order that the length of disability may be shortened and that they may undergo immediate treatment. This latter feature has been very helpful as departmental heads are constantly sending employees to the medical department for examination when an employee shows signs of not being well, a condition which, of course, shows up very quickly in his production. In one of the large plants in Hudson County the foremen are required to report cases of this kind, and it is surprising to see how many observation cases have been detected by this method.

At the Pittsburgh Westinghouse Electric Plant there was often hesitancy among employees about going to a sanatorium for treatment, but this has been overcome in part by having photographs taken of different sanatoriums and permitting the employee to take the photographs home to show to his wife or family so that all would understand to just what kind of place the patient was going. Also, when one of the workers goes to a sanatorium, one or two other employees from the shop go along, expenses paid, so that when they return they will tell all their friends in the shop what a wonderful place a sanatorium is. The cases which are arrested and returned to work are walking delegates for preventive medicine, and they spread this gospel throughout the plant.

In this connection permit me to quote Wade Wright:

> Of particular value in relation to industrial practice are consultation diagnostic clinics for tuberculosis and for cardiac disease. Tuberculosis is rarely recognized in industrial dispensaries yet there are many tuberculous industrial workers. The situation recalls J's comment in "Three Men in a Boat" upon the fact that he had never met, on land, a man who had never known what it was to be seasick, though at sea he came across whole boat loads of them. There is a prejudice in industry against discussion of such dread maladies as tuberculosis.
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> . . . . Among those who suspect that they may be tuberculous, fear of the unknown path ahead, of hospitalization, of relegation to the scrap heap, these serve as powerful deterrents to inquiring minds. One glimpse in a plant by a sturdy, healthy, hopeful graduate of a tuberculosis sanatorium, re-

turned to his former work among his former mates, can do more to uncover clandestine tuberculosis than the taking of many afternoon temperatures and a multitude of short, snappy coughs at the end of expiration.

The return of arrested cases to employment demands real, not fancied, knowledge of working conditions, as well as mechanism for continued observation.

Dr. Hazlett feels very strongly with regard to sanatorium treatment as his records show that the patients who go away lose only about one-half the time lost by those who stay at home for two or three months and finally perhaps go to a sanatorium. He reports a considerable reduction in the number of cases found at the Westinghouse Electric Plant and attributes this to the following:

1. Examination of all new employees.
2. Education of employees.
3. Investigation of all cases of absenteeism.
4. Periodic examinations.
5. Co-operation of superintendents and foremen.
6. Examination of employees returning to work after illness.

Conclusion

It is only by means of continually fighting tuberculosis through the agencies of the physical examination, the finding of early cases, constant medical supervision of the tuberculous, the continued educational campaign, and the proper after-care and placement of those discharged from the sanatorium that the disease can be kept down, and to this end the tuberculosis sanatorium, the tuberculosis association, and industry should work hand in hand. If progress has been made in other age groups in the campaign against tuberculosis let us intelligently bend our efforts to a systematic attack directed against tuberculous cases in industry.

If the cases can be gotten early, the sanatorium stay is shorter, the patient can be returned to industry, and the economic loss that would otherwise be sustained is greatly diminished.

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SILICOSIS WITH LOW INCIDENCE OF TUBERCULOSIS*

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INTRODUCTION

DURING the past fifteen years of observations in the state of Ohio, there have appeared very few reports of silicosis, and these usually from abrasive industries. There have been no reports of excessive tuberculosis associated with silicosis, as from the sandstone quarries. Inasmuch as one of the chief centers of the sandstone industry in America, and the chief center of Berea sandstone, is located in the northern part of the state of Ohio (Lorain County), we made an intensive X-ray examination of all the workers so engaged in 1926. The workmen are employed by two quarry companies, which market grindstones, scythestones, curbing, flagging, breakwater and building stone, and also furnace sand.

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These sandstone quarries were known to pioneers, and were worked as early as 1855. The present activities began about 1870, and the two occupying companies were organized in 1886 and 1903, respectively. The quarries are among the largest and are said to be the deepest sandstone quarries in the world (212 feet).

About 75 per cent. of the workers reside in two small villages, the chief one, South Amherst, having a population of only 944 inhabitants, and the other, Amherst, 2,485 inhabitants; the remaining 25 per cent. live in the country districts around the villages.

In the earlier years the customary day was 12 hours in the summer time and from 9 to $10\frac{1}{2}$ hours in the winter time, but from 1903 to 1918 the standard working day in all departments except the sawmills was 10 hours; from 1919 to 1928, it was 9 to 10 hours, and in the sawmills, 12 hours, except in the last two years when the sawmills have been operated on an average

of 10½ hours per day. The week is 5½ days. All the sawing is done by wet processes, usually with power driven gang saws with a continuous flow of water over them, but there is, nevertheless, considerable fine dust suspended in the atmosphere. While there is considerable labor turnover among the younger and more recently employed men, the older men are fairly steady and there are many who have been employed for from twenty-five to forty years.

FIG. 1.—The Buckeye Quarry, 212 feet deep, South Amherst, Ohio.

FINDINGS IN PRESENT STUDY

A grant from the American Medical Association of $1,000 for X-ray films, other grants and loans, including X-ray equipment largely furnished by the Kelley-Koett Manufacturing Company, Covington, Ky., and totaling upward of $5,000, and the kindest co-operative spirit on the part of all, including the employers and employees, made it possible for one of us (D. J. K.) to proceed with the making of 919 pairs of stereoradiograms on as many employees, using a stationary X-ray outfit at the quarries.[2] All the men had been physically examined by the physicians of the companies within the year, with limited findings of pulmonary afflictions.

[2] Acknowledgment is due Dr. Kennon Dunham of Cincinnati, a specialist in tuberculosis, for reviewing all films diagnosed as tuberculosis, and for checking over the several classifications of silicosis.

FIG. 2.—Quarry scene, showing channeling machine and wet drilling process.

FIG. 3.—Curbing yard, making split curbing.

FIG. 4.—Showing planing and handling of curbing stones.

FIG. 5.—The building stones are sawed by gang saws in the mill building (right).

A summary of our preliminary findings was published in the August, 1927, issue of the *American Journal of Public Health* (1). Our completed data, in brief, are shown in Table 1 and Chart 1.

FIG. 6.—Turning grindstones.

Thus, from Table 1, stereoradiographic chest examinations show 260, or 28.5 per cent., of the 912 workers (with readable films) to have various stages of silicosis, and 238, or 26.1 per cent., additional workers to have increased fibrosis, but there were only 13, or 1.4 per cent., with silicosis plus tuberculosis, and 5, or 0.5 per cent., with tuberculosis without silicosis, or a total of 1.9 per cent. with tuberculosis. Furthermore, of the 260 silicotics, but 13, or 5 per cent., had tuberculosis. The total tuberculosis figure of 1.9 per cent. for these 912 workers is practically the same as the usual tuberculosis incidence cited for average industries in the United States (2), and that found to exist in the typical population by the Framingham Demonstration (3, p. 10) which showed 1 per cent. of active cases and 1 per cent. of arrested cases.

It will also be seen from Table 1 that the average exposure of 16.24 years for the initiation of beginning silicosis is over twice that reported by the South African investigators (4,

p. 279), which is 7.5 years.[3] In view of the high content of silica (SiO_2)—92 to 97 per cent.—in the Ohio sandstone, this delayed silicosis is, in itself, remarkable.

There was, likewise, a surprisingly low incidence of disability in workers with silicosis: Cough was a prominent symptom in only twenty-five, shortness of breath in nineteen, expectoration in eleven, loss of weight in ten, and pain in the chest in eight. Sputum examinations were not made. These major symptoms of tuberculosis were, however, about equally as

TABLE 1.—STEREOSCOPIC X-RAY CHEST FINDINGS OF ALL WORKMEN EMPLOYED, BY DEGREE OF SILICOSIS INVOLVEMENT, MEDIAN AGE, AND AVERAGE YEARS OF EXPOSURE

CLASSIFICATION	NO.	PER CENT.	MEDIAN AGE	AVERAGE EXPOSURE
			yrs.	*yrs.*
Essentially negative	409	44.5	27	3.78
Increased fibrosis	238	25.9	36	7.41
Beginning silicosis[1]	180	19.6	40	16.24
Moderately advanced silicosis[2]	45	4.9	52	21.82
Far advanced silicosis[3]	22	2.4	49	27.05
Silicosis plus tuberculosis[3]	13	1.4	47	16.15
Tuberculosis without silicosis	5	0.5	42	13.00
Films not readable	7	0.8	..	.....
Totals	919	100.0	..	.....

[1] This stage corresponds, we believe, to the ante-primary stage of the South African reporters. Our description reads:

"Beginning Silicosis—In addition to a generalized fibrosis involving the bronchial trunks radiating to all parts of the lung field, there is a diffuse, discrete, punctate mottling, which seems to follow the bronchial trunks into the lung substance and which in the stereoscope appears as buds on the branch of a tree. We have arbitrarily given the name of 'bronchial buds' to these discrete shadows."

[2] This stage corresponds, we believe, to the primary stage of the South African reporters. Our description reads:

"Moderately Advanced Silicosis—The same changes are noted as in beginning silicosis except that we see the bronchial buds more widely separated and of a larger size."

[3] These stages correspond, we believe, to the secondary stage of the South African reporters. Our description reads:

"Far Advanced Silicosis—The same shadows are here again seen as observed in the two previous groups excepting that now the enlarged buds of the moderately advanced stage have coalesced and become conglomerate, and we find consolidation taking place. In addition the viscera of the mediastina may be displaced to one side or the other due to the contraction of the fibrous tissue. In several of our cases the trachea and heart shadows were considerably distorted from their normal relations."

"Silicosis with Tuberculosis— . . . . showing combined pathology of silicosis and tuberculosis."

[3] Watkins-Pitchford (5, p. 125) shows that the average for European miners in the gold mines of the Rand is 9.44 years for the seven-year period ending 1923 to 1924, while for the year 1923 to 1924, it was 10.25 years.

frequent in the 71.5 per cent. who did not show silicosis. Hemoptysis was found in but one case.

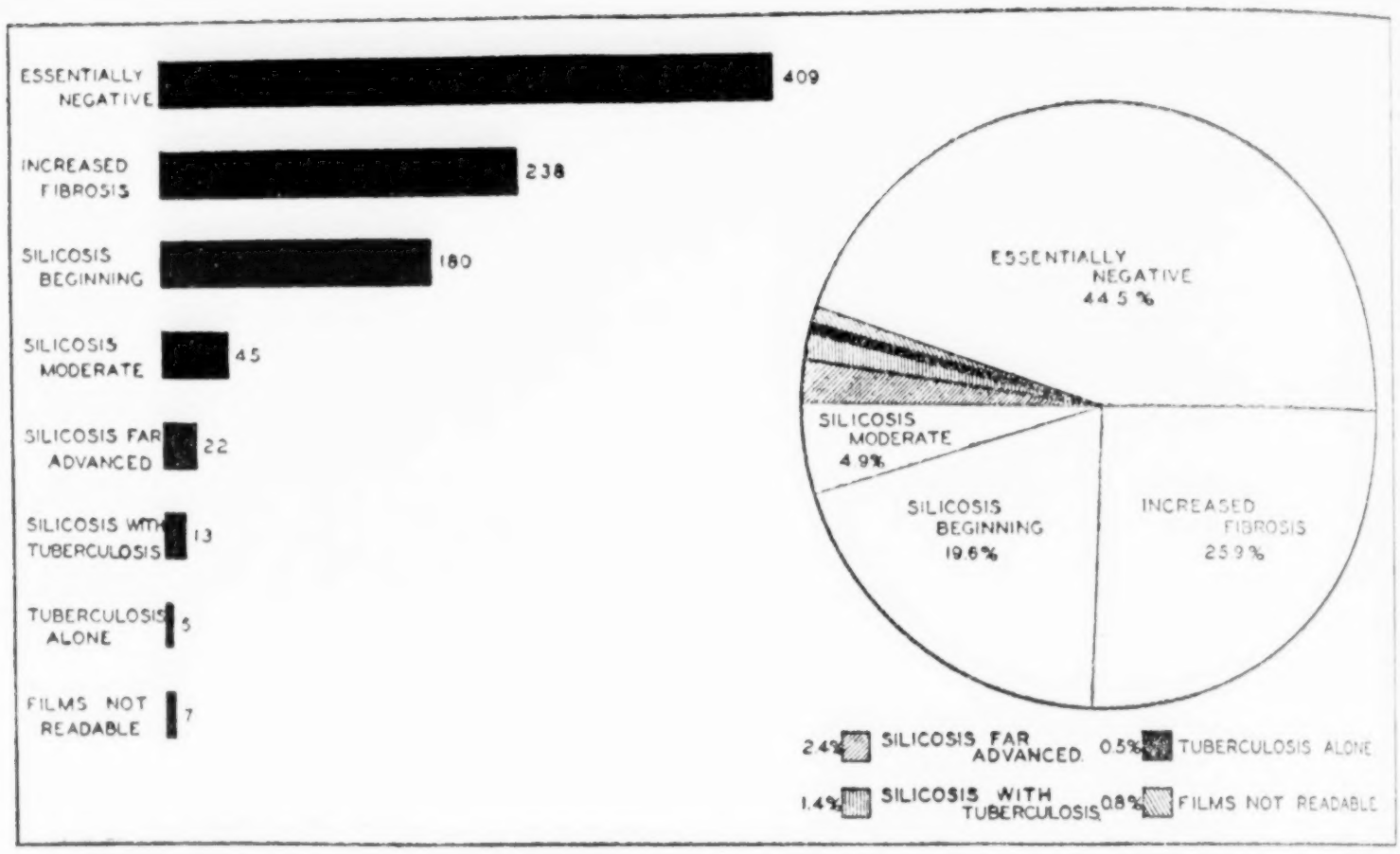

CHART 1.—Showing the extent of silicosis and other X-ray chest findings in 919 quarry workers.

Fearing that the more disabled workmen were not at work, we next turned to the community health as expressed in tuberculosis figures. Here one of us (C. D. B.) had recourse to the tuberculosis mortality figures for Lorain County. Table 2 shows the records for 1921 to 1926, inclusive, and the population figures of the 1920 Census, which were used in determining the average annual rates per hundred thousand (see also Chart 2).

The total deaths from tuberculosis for the entire rural and village population of Lorain County, both sexes, were 111—an average of 18.5 deaths per year, or an average annual rate of 56.3 per hundred thousand; the total deaths for the rural districts and villages exclusive of the quarry villages were 89, or an average annual rate of 50.4; the total deaths for the quarry villages alone were 22, or an average annual rate of 106.8; and the total deaths for Lorain City, 140, or an annual rate of 62.6. Thus, while these figures are small, there was apparently an approximately doubled tuberculosis death rate in the quarry district (villages and township) as compared with the rest of the rural and village population of the county, and this rate was 70.6 per cent. in excess of that of the neighboring industrial city of Lorain, Ohio.[4]

Lorain County, however, has a much lower tuberculosis death rate, 56.3, both sexes, than the average

[4] Lorain's chief industry is, by far, the National Tube Company, a subsidiary of the United States Steel Corporation, which employs some 7,000 to 9,000 persons and was one of the first establishments in America to install a Safety and Welfare Division, upon which millions of dollars have been expended. This is undoubtedly reflected in Lorain's low tuberculosis rate.

for the state of Ohio, 82.5, for the period in question (Table 3). Likewise, industrial districts invariably show much higher tuberculosis rates than rural, village, or city communities. Hence, the tuberculosis rates cited bear out our previous findings of no more than an average industrial tuberculosis incidence in the industrial group considered.

TABLE 2.—TUBERCULOSIS IN LORAIN COUNTY (ALL FORMS, BOTH SEXES)

	POPULATION 1920 CENSUS	NO. OF CASES REPORTED, 1921–1926	NO. OF DEATHS REPORTED, 1921–1926	AVERAGE ANNUAL CASE RATE PER 100,000	AVERAGE ANNUAL DEATH RATE PER 100,000
Lorain County general district (*i.e.*, outside of cities having 5,000 or more population)	32,843	171	111	86.8	56.3
Lorain County general district exclusive of Amherst and South Amherst villages.	29,414	143	89	81.0	50.4
Amherst and South Amherst villages (where most of the employees reside)	3,429	28	22	136.1	106.8
Lorain City (an industrial city 7 miles distant)	37,295	249	140	111.3	62.6

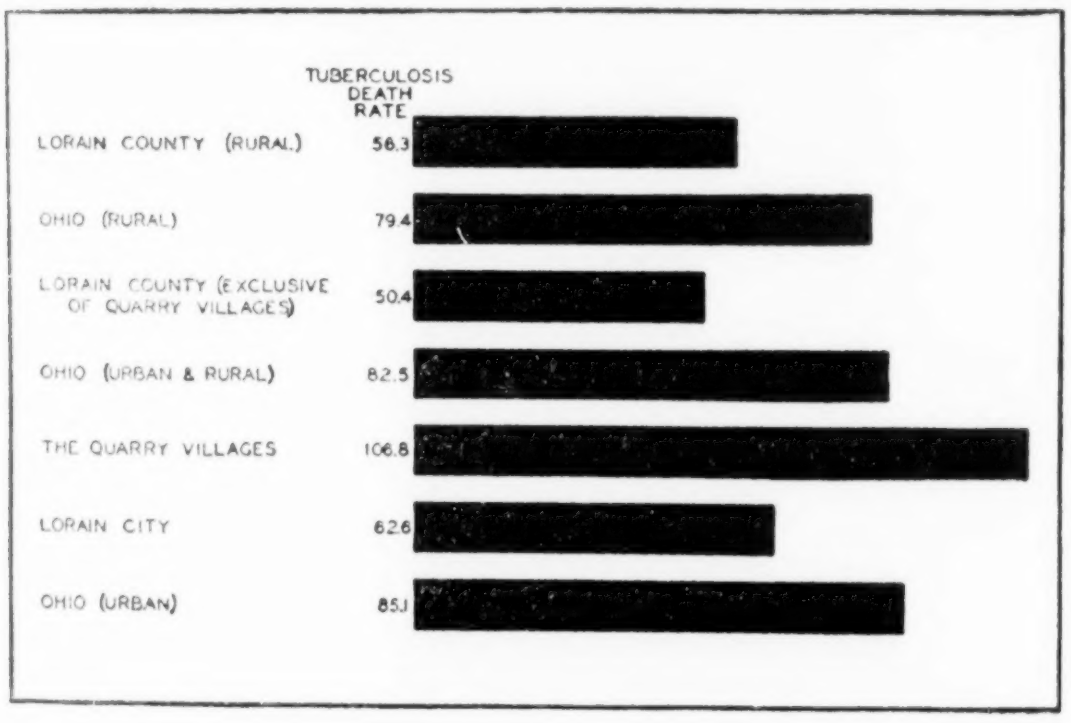

CHART 2.—Showing comparison between tuberculosis death rates per 100,000 population, 1921 to 1926, inclusive, in pertinent areas, Ohio.

Some six chemical analyses are on record (6) showing the nature of the sandstone, two of which are presented in Table 4. Note the high percentage of silica (SiO_2).

The specific gravity of the sandstone ranges from 2.143 to 2.335 and the porosity from 15.87 to 16.23 per cent., depending on the variety of the stone examined. An average dry weight

per cubic foot is 140 pounds. The color is buff gray, often showing brown spots due to iron deposits.

Comparison of Present Study with Other Silicosis Reports

In the United States, a study which most nearly compares with our own was that made by Jarvis, and published by Hoffman (7, p. 156), in the granite stone industry of Barre, Vt., where the rock worked had an average silica content of 69.89 per cent. (about 25 per cent. less than that in our study). Here, 183 workmen, or 51.1 per cent., out of 358 radiographed satisfactorily, showed silicosis, and there was an incidence of 148 cases of tuberculosis, or 34.7 per cent., in 427 examinations (evidently selected out of a total of 1,085 employees). Hoffman also found (*loc. cit.*, p. 27) that the mortality rate from pulmonary tuberculosis among granite cutters in Vermont was 1064.5[5] per hundred thousand as compared with 108.3[6] for the general adult population (20 years of age and over) for the state of Vermont.

More recently Hague and McBain (8) have completed, in connection with gold mining in northern Ontario, one of the most extensive surveys on the North American Continent along the lines of pneumonokoniosis. Approximately 4,000 miners were examined. On the basis of the South African nomenclature, ninety-four had compensable silicosis, and 247, or 6.1 per cent. of the total, showed positive or probable tuberculosis. While these investigators report very low incidence

[5] Exclusive of the last three months of 1918.

[6] 1915 to 1917.

TABLE 3.—TUBERCULOSIS DEATH RATE (CRUDE) PER 100,000 POPULATION, FOR THE STATE OF OHIO, 1921 TO 1926, INCLUSIVE, BY URBAN AND RURAL DISTRIBUTION

YEAR	RATE PER 100,000		
	Urban	Rural	Annual
1921	92.7	83.8	89.1
1922	88.9	79.5	85.2
1923	87.8	82.6	85.8
1924	82.9	79.7	81.7
1925	78.1	72.9	76.1
1926	79.9	77.9	79.1
Average....	85.1	79.4	82.5

TABLE 4.—CHEMICAL ANALYSIS OF THE SANDSTONE, SOUTH AMHERST QUARRIES

A. Sandstone from Quarry No. 6[1]

	Per Cent.
Silica (SiO_2)	92.15
Alumina (Al_2O_3)	3.85
Ferric oxide (Fe_2O_3)	1.40
Titanium oxide (TiO_2)	0.40
Calcium oxide (CaO)	0.50
Magnesium oxide (MgO)	0.20
Loss on ignition	1.70
Total	100.20

B. Specimen of Gray "Canyon"[2]

	Per Cent.
Silica	97.00
Iron carbonate	2.30
Calcium carbonate	1.86
Magnesium carbonate	0.97
Water	0.70
Total	100.04[3]

[1] Analysis by Prof. D. J. Demorest, Ohio State University.

[2] Analysis by Prof. J. H. Salesbury, State Geologist.

[3] This total should read 102.83, but it is impossible for the authors hereof to make the correction.

of silicosis, due, they state, undoubtedly to a great admixture of other dusts with the silica, they still find that "tuberculosis is the predominating serious factor but does not exist to nearly the same extent or virulence as that of South Africa."

In a letter under date of May 7, 1928, Dr. D. G. Robertson, Director, Division of Industrial Hygiene, Commonwealth of Australia, Melbourne, summarizes as follows certain Australian silicosis studies, which in the case of surface workers may be fairly compared with our own (*miners* are largely underground workers, except where otherwise specified):

> The Technical Commission on Miners' Phthisis and Pneumonoconiosis at Broken Hill (9) in 1921–1922 examined 2,618 *miners*, and of these 266 presented signs of pneumonoconiosis, and 107 uncomplicated tuberculosis. Of the 266 men with pneumonoconiosis, 102, or 38 per cent., had pulmonary tuberculosis.
>
> The Technical Committee of Inquiry to Investigate the Prevalence of Silicosis and Tuberculosis among *Stonemasons*, *Quarrymen*, *Sewer Miners*, and *Rockchoppers* in the Sydney district (10), 1924, examined 716 men, 123 of whom were found to exhibit signs of silicosis. Of these 123 men 38, or 31 per cent., were complicated by tuberculosis. Another 16 men were found to be suffering from simple pulmonary tuberculosis.
>
> In 1922, 136 working *miners* were examined clinically and radiologically at the Commonwealth Health Laboratory, Bendigo, and of these 90 were found to be suffering from silicosis. Eight of these 90 men, or 9 per cent., had tuberculosis as a complication.
>
> The Commonwealth Department of Health in 1925–1926 examined 4,067 *mine employees* in Western Australia (11). Of these 798, or 19.6 per cent., presented definite evidence of pulmonary silicosis, and 155, or 3.8 per cent., of tuberculosis, 12 of the latter having tuberculosis without silicosis. [This is equivalent to 17.9 per cent. tuberculosis in the silicotics.]

This last report also shows that *surface workers* numbered 1,759, of whom 117, or 6.6 per cent., had silicosis (about one-fourth the rate in our investigation); twenty-seven, or 1.5 per cent., had silicosis plus tuberculosis, and six, or 0.3 per cent., had tuberculosis alone, the tuberculous totaling thirty-three, or 1.8 per cent., of the total examined (and 27.3 per cent. of the incidence rate for silicosis).

In our study, of seventeen trade processes showing from 20 to 56.5 per cent. of silicosis and involving 661 men, 484, or 73.2 per cent., of the workers were employed out of doors. (See Table 5 and Chart 3.)

Heffernan (12), in 1926, found that workers might be exposed to silica dust, as in the manufacture in Derbyshire of bricks from pocket silica sand, without the development of silicotic fibrosis, but in no reports, to our knowledge, has any considerable percentage of silicosis been reported without an associated high incidence of tuberculosis, usually in the neighborhood of from 20 to 30 per cent. or more. In no other studies, to our knowledge, has a silicosis figure as high as 28.5 per cent. been associated with a total tuberculosis figure as low as 1.9 per cent. The question therefore arises whether silicotic fibrosis is necessarily provocative of tuberculosis. A study of races is shown in Table 6 and Chart 4.

It will be seen that, in descending order, the Russian, Polish, Assyrian and Syrian, Scotch, and Slavic races have the highest relative susceptibility to silicosis; the Hungarian and Italian races the next highest; the English, German, and Swiss the next; and the American, miscellaneous, Irish, and Scandinavian the lowest. Of

TABLE 5.—YEARS OF EXPOSURE (MEDIAN) BY OCCUPATIONS AND BY SILICOSIS INVOLVEMENT FOR 907 SANDSTONE QUARRY WORKERS

TRADE PROCESS	GRAND TOTAL		NON-SILICOTIC		SILICOTIC		
	No.	Yrs.	No.	Yrs.	No.	Yrs.	Per Cent.
Grindstone workers[1]	23	15	10	3	13	23	56.5
Curb yard workers	80	15	42	3	38	25	47.5
Saw setters[1]	22	8	12	2	10	16	45.4
Hookers	34	4+	20	3	14	11	41.2
Rockmen	154	4+	92	1+	62	17	40.3
Riggers	15	5	9	5	6	6	40.0
Sawyers[1]	23	12	14	11	9	13	39.1
Derrick runners	37	14	23	12	14	15+	37.8
Curb yard laborers	15	3	10	1	5	15	33.3
Channel machine operatives	82	3	56	1	26	12	31.7
Mill yard laborers	23	2	17	1	6	11+	26.0
Machinists[1]	35	10	26	3	9	21	25.7
Quarry laborers	30	1	23	1	7	14	23.3
Hoisters[1]	27	14	21	8	6	14+	22.2
Planers[1]	37	4	29	3	8	14	21.6
Steam shovel operatives	14	2+	11	1	3	19	21.4
Engineers and firemen (stationary)[1]	10	8	8	2+	2	16	20.0
Cranemen	21	12	17	7	4	23+	19.0
Railway employees	27	4	22	4	5	2	18.5
Pipe fitters	6	1	5	1	1	25	16.7
Powermen[1]	13	12	11	12	2	15	15.4
General laborers	33	1	29	1	4	10	12.1
Millwrights[1]	9	18	8	13	1	23	11.1
Drillers	46	2	43	1+	3	14	6.5
Blacksmiths[1]	40	3	38	3	2	18	5.0
Clerks[1]	16	8	16	8	..	....	....
Carpenters[1]	15	3	15	3	..	....	....
Electricians	10	5	10	5	..	....	....
Boiler makers[1]	4	4	4	4	..	....	....
Miscellaneous	6	25	6	25	..	....	....
Totals	907	....	647	....	260	....	28.7

[1] These trade processes have inside employment; this feature appears to have had little influence in the production of silicosis.

the thirteen cases of silicosis plus tuberculosis, and the five cases of tuberculosis without silicosis (these five are not shown in Table 6), four were German, three Russian, two American, and the remaining nine cases were scattered among as many races. While it is probably true that certain races appear more susceptible to silicosis than do others, this undoubtedly depends more upon their respective exposures in various occupational processes than upon race. These race statistics show nothing, therefore, to explain the low incidence of tuberculosis.

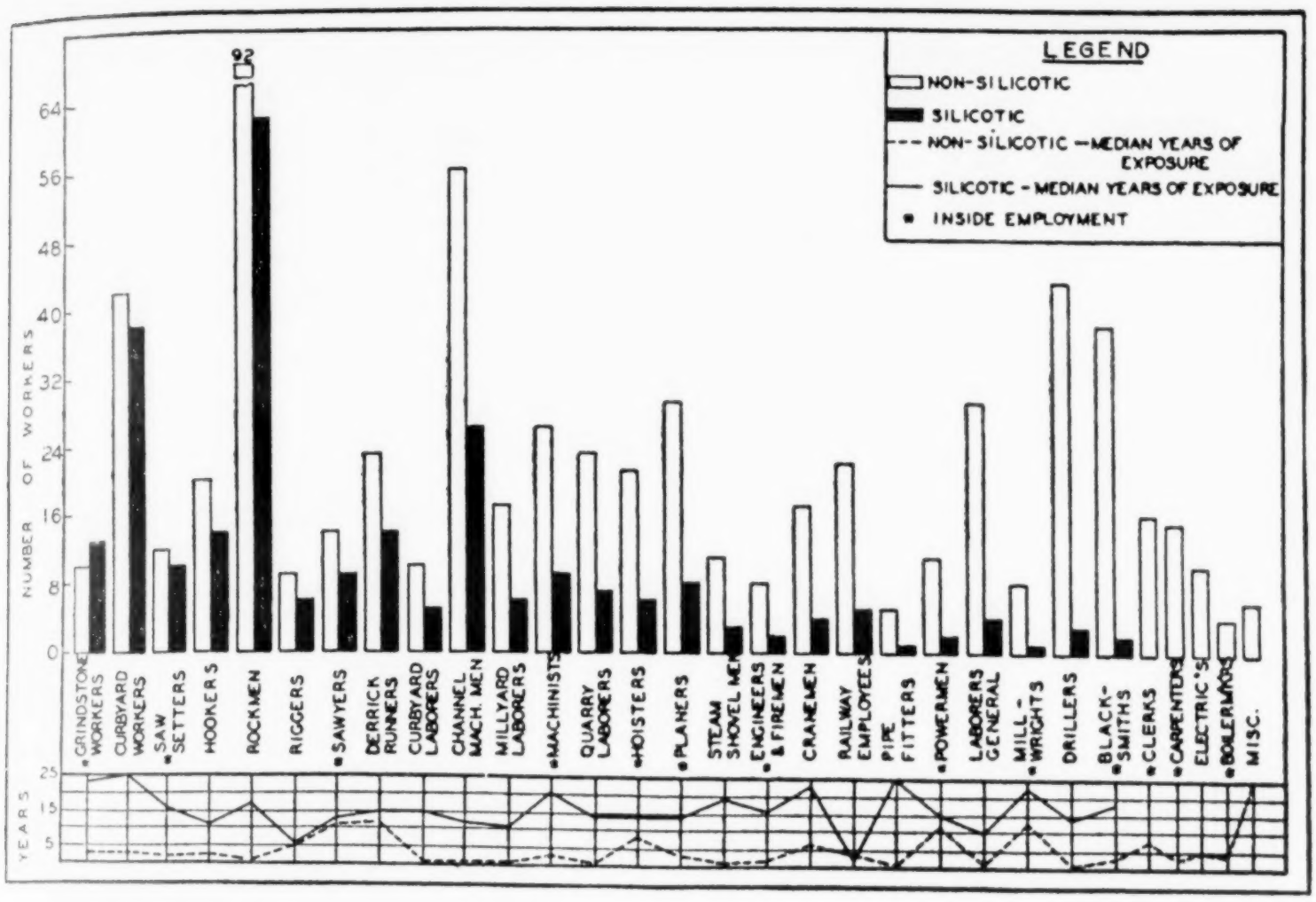

CHART 3.—Trade processes of quarry workers in relation to silicosis, indoor and outdoor employment, and years of exposure.

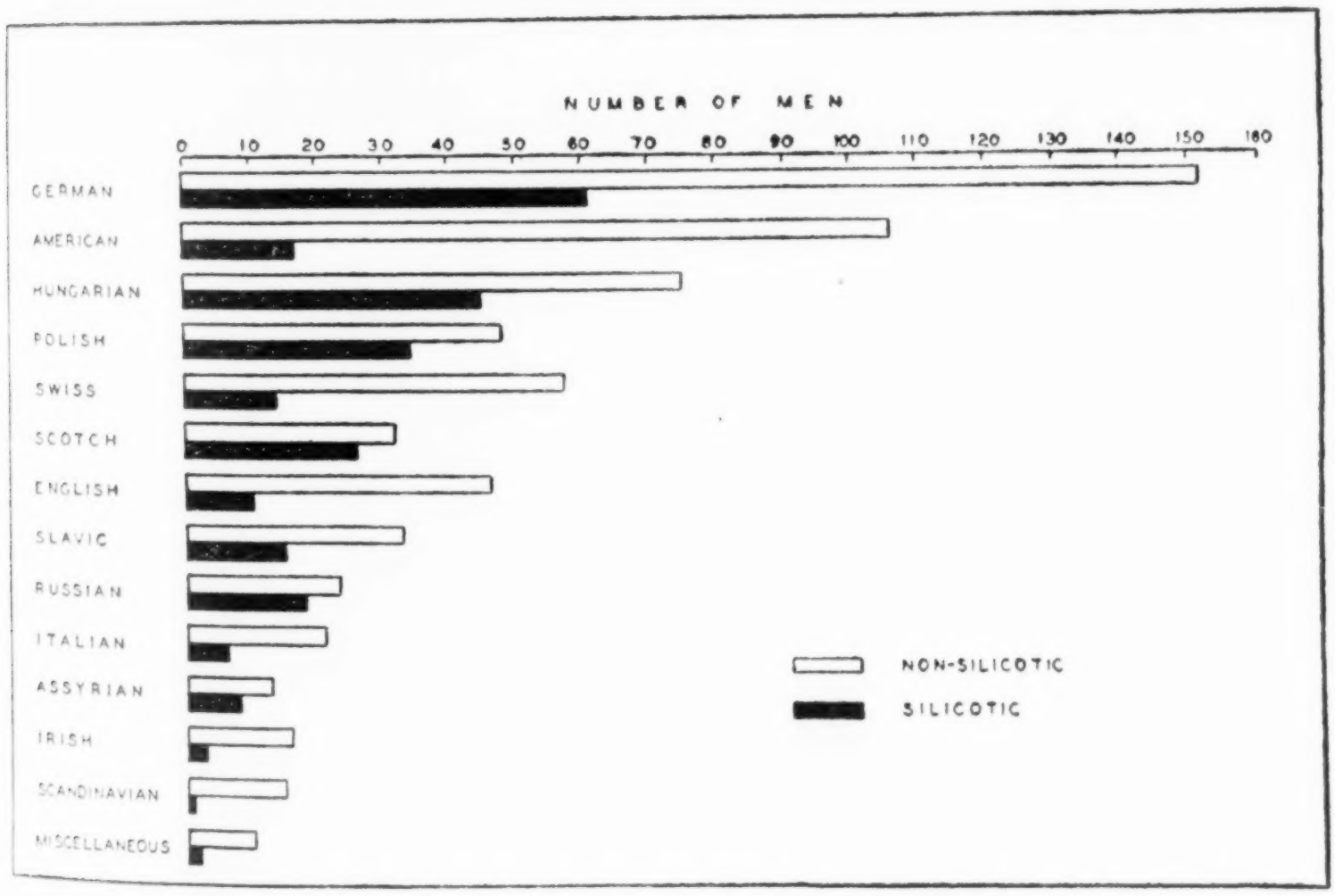

CHART 4.—Predominant racial origins of quarry workers, and silicosis.

TABLE 6.—YEARS OF EXPOSURE (MEDIAN) BY RACES AND BY SILICOSIS INVOLVEMENT FOR 907 SANDSTONE QUARRY WORKERS[1]

RACE	GRAND TOTAL		NON-SILICOTIC[2]		SILICOTIC[3]			RELATIVE SUSCEPTIBILITY FACTOR[4]
	No.	Yrs.	No.	Yrs.	No.	Yrs.	Per Cent.	
German[5]	213	10	152	3	61	24	28.6	1.19
American[5]	123	2	106	2	17	18	13.8	0.77
Hungarian[5]	120	5	75	2	45	23	37.5	1.63
Polish[5]	82	4	48	2−	34	15−	41.5	2.77
Russian[5]	41	5+	23	4	18	13	43.9	3.38
Scotch[5]	58	5+	32	2	26	18	44.8	2.49
English[5]	56	5	46	3+	10	14	17.8	1.27
Swiss[5]	71	3	57	3	14	17+	19.7	1.16
Italian[5]	27	11	21	5	6	15	22.2	1.48
Irish[5]	19	3	16	2	3	26	15.8	0.61
Assyrian and Syrian	21	11	13	6	8	14−	38.1	2.72
Slavic	48	2	33	1	15	15	31.2	2.08
Scandinavian	16	2	15	2	1	23	6.2	0.27
Miscellaneous	12	2	10	1	2	24	16.7	0.69
Totals	907	....	647	....	260	....	28.7	....

[1] Of the 919 workers, 7 are omitted because the films were not readable, and 5 tuberculosis cases are omitted which showed no silicosis involvement. These were: 1 Hungarian and 1 English with 1 year's exposure, 1 Slavic at 5 years' exposure, 1 Polish at 18 years' exposure, and 1 Irish at 40 years' exposure.

[2] Consists of essentially negative, and increased fibrosis.

[3] Consists of beginning, moderately advanced, and far advanced silicosis, and silicosis with tuberculosis.

[4] Obtained by dividing the percentage of silicotics by the median years of exposure.

[5] Pure and mixed stocks combined.

It takes only a glance at the statistics or the charts to note that the degree of silicosis has varied in proportion to the years of exposure except that silicosis plus tuberculosis manifested itself as early as beginning silicosis, *viz.*, after about fifteen years' exposure (Chart 5). It is also interesting to note that few men suffered from silicosis under 25 years of age, but that at 34 years of age there were as many men silicotic as non-silicotic, and, again, that after 44 years of age there were usually as many and sometimes more silicotics than non-silicotics (Chart 6).

Heffernan (12) suggests that the harmlessness of silica dust, in the production of silicosis, may lie in the fact that the quartz grains are coated with a kaolinitic or clayey material. Feeling that some such explanation might also account for the presence of silicosis with low incidence of tuberculosis, we asked Prof. Wm. J. McCaughey, Head of the Department of Mineralogy, Ohio State University, to make an examination of samples

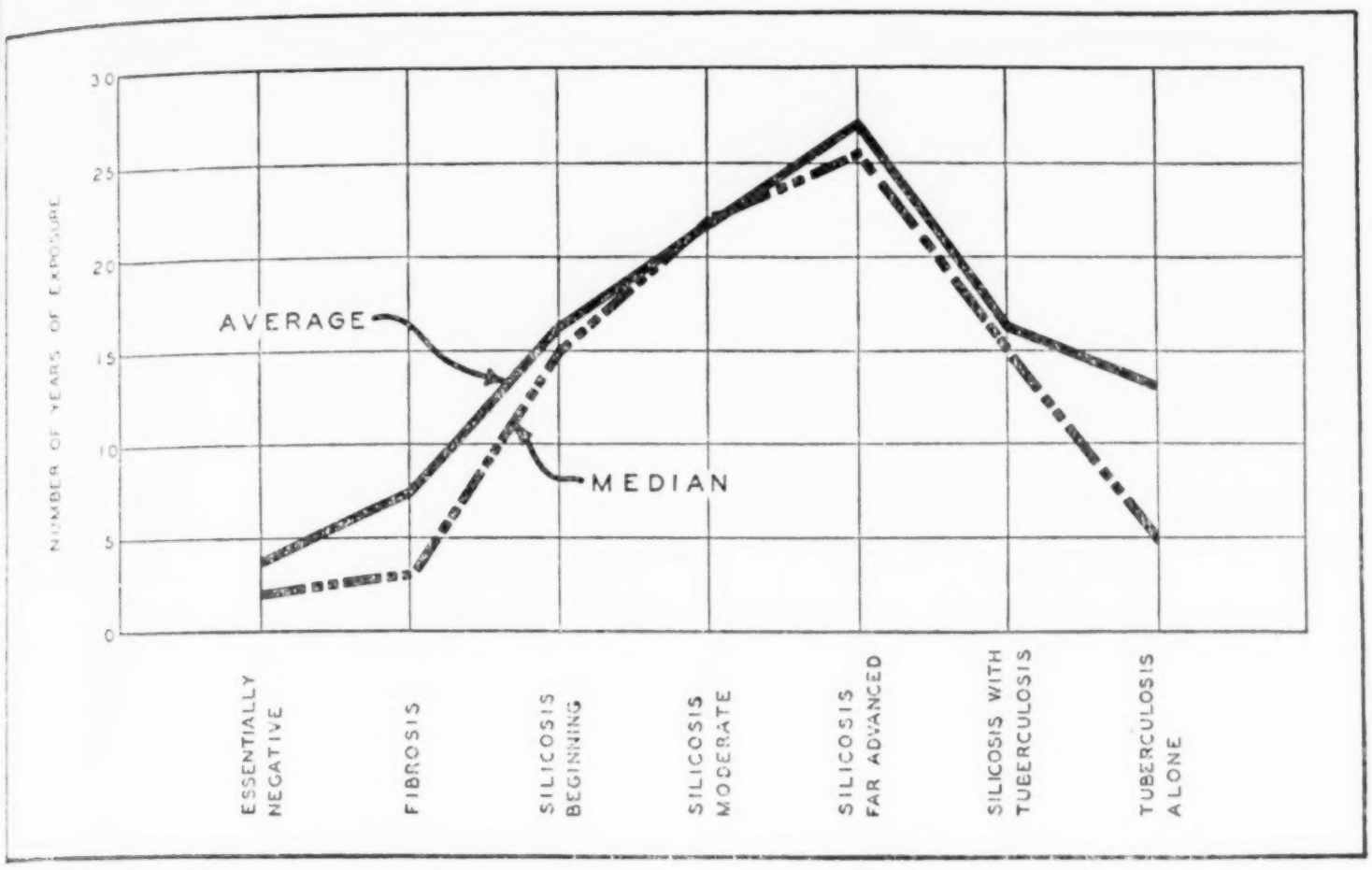

CHART 5.—Showing the average and median number of quarry workers by years of exposure and by extent of silicosis involvement.

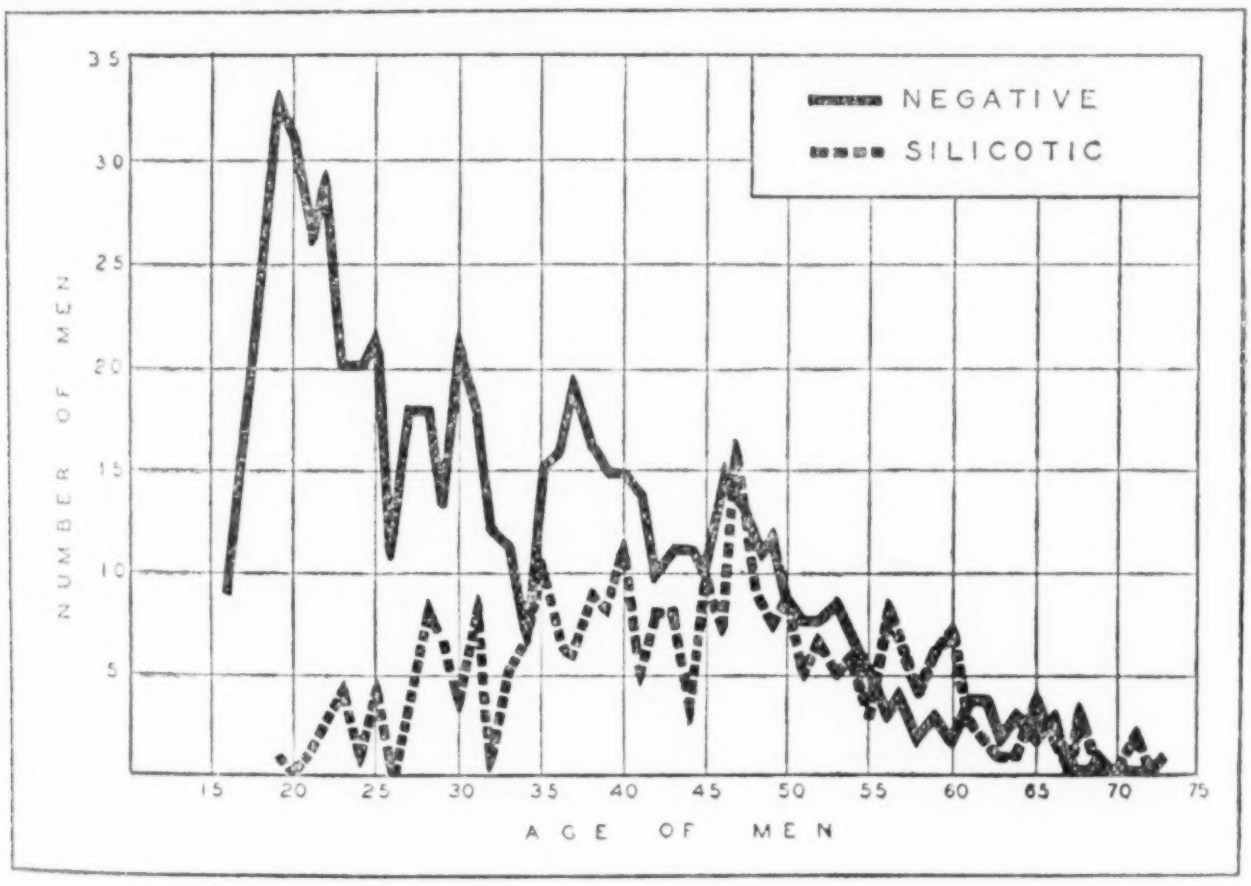

CHART 6.—Showing the number of quarry workers in each year of life, and by silicosis involvement.

of the sandstone for us. He reports as follows (13):

> This rock is a sandstone composed of subangular quartz fragments of average diameter, 0.25 mm. The mineralogical composition of this rock is rather varied. The predominant mineral is *quartz* (H =7)[7]

[7] H = hardness.

which exists as clear, transparent grains, and also in much smaller amounts as chalcedony. While the quartz particles are subangular, they do not come to sharp points, but are rounded off somewhat. *Ankerite* (carbonate of Ca, Mg, Fe) is the next most abundant mineral. It occurs in single grains scattered through the rock, as interstitial mineral between other grains. It is not evenly distributed in the rock, but forms discontinuous bands through the rock and is probably secondary, as it so frequently "moulds" the other minerals. The index of refraction of the ordinary ray of this carbonate mineral is 1.715, which indicates ankerite of a composition of 60 molecular per cent. of $CaMg(CO_3)_2$ and 40 molecular per cent. $CaFe(CO_3)_2$. Ankerite is an iron rich dolomite and has a hardness of 3.5. *Feldspar* is the next most abundant mineral occurring in considerable quantity as orthoclase, microcline and albite (H=6). The orthoclase is very much altered to a soft kaolin and sericite. The microcline and albite are as fresh unaltered fragments. *Pyrite* is also present in the thin section as tiny particles (H=6) often showing a halo of iron oxide, due to weathering and oxidation. *Other minerals* present as accessory minerals, but in amounts probably not as much as 1 per cent. of each, listed in the order of their occurrence are iron oxide (limonite); hornblende (H=5.5); zircon (H=6.5); the micas, muscovite and chlorite (H=2); and rutile (H=6.5).

The mineralogical constitutions of the two dusts or powders do not differ of course from the rock itself. In the heavy dust the ankerite amounts to 5 to 10 per cent. . . . The light powder has a much lower content, probably around 3 or 4 per cent. The light dust is much finer grained than the dark dust, but the light dust is darker in color, due to iron oxide stain. The pyrite in the dust evidently oxidizes readily for it is not easy to find pyrite (FeS_2) in the dust, but instead stains of oxide and particles of limonite ($2\,FeO_3 \cdot 3\,H_2O$).

The ankerite frequently shows signs of oxidation turning to a brownish color and showing characteristic absorption of this mineral.

I would hesitate to discuss the physiological effects of any of these minerals in their deposition in the lungs of workers . . . , but I might point out the properties of two of the minerals present, one in considerable amount, *viz.*, ankerite. It might have some bearing on the problem that the number of those dying from tuberculosis is such a small part of those suffering from silicosis.

Ankerite is a solid solution of carbonates of calcium, magnesium and ferrous iron, and gives a slight alkaline reaction. Would the astringent property of the iron be of any significance? It is a mineral that decomposes easily, both because it is a carbonate very slightly soluble in water (about that equal to calcite or dolomite) and is easily decomposed by the oxidation of the ferrous carbonate to form the hydrated oxide of iron.

The pyrite in this sample, while small in amount, seems to be very readily oxidized and of course would form ferrous sulphate, and sulphuric acid. Would the oxidation of the pyrite in the lung, combined with its astringent effect, be of prophylactic value, against tuberculosis?

It will be noted from the foregoing description of the rock that (1) the quartz (silica) crystals are obtuse rather than acute angled and, while it seems generally accepted that the physical structure of particles of silica, in the nature of sharp or spiculated edges and points, is secondary in the cause of lung pathology, we believe this fact should be noted herewith; and (2) the matrix or bond holding the quartz granules together, and representing from 3 to 10 per cent. of the mass, is of a rather rare mineral called ankerite, composed of carbonates of the earthy metals and iron, of silicates, of kaolin forming substances, and of the sulphides and oxide of iron. Some of the matrix substances mentioned, when in sufficient amount, have been

shown by others to have a protective influence against the silicotic and the tuberculous processes in the lungs.

We are, of course, without immediate proof that the petrographic characteristics of this rock explain the anomaly discussed, *viz.*, high incidence of silicosis with low incidence of tuberculosis, but a presentation of all the facts at hand would appear to support this assumption. It would seem highly advisable that future silicosis studies should be correlated with both the chemical and the petrographic characteristics of the stone dust involved.

Summary

One of the largest and deepest sandstone quarry districts in the world has been worked in northern Ohio for over fifty years. Employment has been fairly steady for years. Many of the workmen are engaged in the elaboration and dressing of the stone in addition to quarrying.

A stereoscopic X-ray examination was made of each of the 919 workmen, of which number the films of 912 workmen were readable. Of this latter number, pulmonary pathology was found in 55.1 per cent., including 28.5 with silicosis in various stages. The total tuberculosis, however, was but 1.9 per cent. Likewise general disability was low. These findings check relatively closely with those of the tuberculosis statistics for the community. The period for developing silicosis, namely, 16.24 years, is over twice that reported elsewhere. The rock has an average content of from 92.15 to 97 per cent. crystalline silica (SiO_2).

A study of silicosis reports throughout the world indicates that tuberculosis is usually present in from 20 to 30 per cent. or more of the cases of silicosis, but of our 260 men with silicosis only thirteen, or 5 per cent., had tuberculosis.

An analysis of ages, years of exposure, trade processes, whether indoor or outdoor employment, race stocks, and the chemical composition of the rock fails to offer an explanation of the anomaly. A careful petrographic study of the rock shows that the crystals are obtuse rather than acute angled and that the matrix or bond holding them together (which chemical analysis shows is not over 3 to 8 per cent. of the mass), is composed of carbonates, silicates, kaolin forming substances, and the sulphides and oxide of iron. Whether or not the nature of this matrix offers an explanation we have no immediate proof, but such would seem probable. We suggest that other silicosis studies should include a careful analysis of the rock itself, from both chemical and petrographic points of view.

For this investigation the authors wish to acknowledge the support of the Committee on Scientific Research of the American Medical Association (Grant 88); the Graduate School Fund of the Ohio State University; the X-Ray Department of the Starling-Loving University Hospital; the loan of several thousand dollars' worth of high class X-ray equipment by the Kelley-Koett Manufacturing Company of Covington, Ky.; the services of representatives and experts from the Eastman Kodak Company and others; and the wholehearted support of the officials of the Ohio Quarries Company and the Cleveland Stone Company in whose quarries the studies were made.

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STUDIES ON EXPERIMENTAL PNEUMONOKONIOSIS. IV. THE SEPARATION OF PARTICULATE MATTER SMALLER THAN SCREEN SIZES INTO GRADED FRACTIONS*

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EVIDENCE from many sources has led to the generally accepted opinion that free silica is a particularly injurious industrial dust when inhaled by workmen. In seeking to explain this injurious quality, several suggestions have been offered, based upon various forms of experimental evidence. It has been proposed that the hardness and the sharpness of the inhaled particles produce sufficient irritation to bring about the pathologic changes associated with silicosis. Again, it has been suggested that the silica particles dissolve in the alkaline juice of the lung and give rise to the highly toxic substance, silicic acid. Another explanation is based on the theory that the inhaled particles behave like the colloidal sols of silicic acid, which adsorb various substances and consequently produce reactions.

Because of the lack of a generally accepted explanation of the cause of the changes encountered in silicosis, this laboratory has proposed to test as nearly quantitatively as possible the various theories offered. The first requirement in this program was to obtain dusts of the sizes found in the lungs of silicotic individuals. Greenburg (1, p. 767) has stated that:

> . . . . It is also of much value to have knowledge of the weight of the dust; but because of the fact that it is practically impossible to separate the particles less than 10 microns in size from those over 10 microns in size, and thus obtain the weight of the injurious particles (those capable of gaining access to the lung tissue), and also because one large particle may weigh many hundreds of times more than a smaller one, the weight of a given sample of dust must be used only as an additional guide in the interpretation of results, and then with some degree of caution.

The method to be described not only has been used to obtain clean-cut separations of particles greater than 10 microns from those less than 10 microns; but it has provided a means of securing graded lots of particles ranging from 0.5 micron upward into the screen sizes. Quantities of these various separations sufficient for analysis and for experimental work with animals have been secured. The number of particles per gram of dust has been determined for quartz and will soon be reported in another paper.

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The separation of particles by sedimentation has been employed both in the laboratory and in industry for many years. In general, the methods employed consist in settling dust in fluids ranging from air to liquids of varying specific gravity and viscosity. When particles which differ in size but not in specific gravity are suspended in a fluid, they settle at varying rates, owing to the difference in the resistance offered to the particles by the fluid. Large particles with a relatively small surface of resistance per unit of mass settle more rapidly than finer ones which are still sufficiently large to settle out. These large particles are therefore the first to appear in a sediment from a suspension, or they collect in the lower layer of a suspension which starts settling from the upper surface of a fluid. A given sample of dust may therefore be roughly graded into fractions, either by collecting the sediments after various periods of settling, or by withdrawing different layers of the fluid suspension as soon as the larger particles have reached the bottom of the container.

When air is used as the suspending fluid, all but the very fine particles are settled out rapidly. Convection currents, however, are troublesome, and the mechanical difficulties encountered in drawing off separate fractions of the suspension do not adapt the method to laboratory apparatus. It has also been noted that the very finest particles tend to clump when they collide with each other in the air and then settle as a single large particle. This method, however, is useful for obtaining extremely fine dusts, since particles which remain in suspension after three hours of sedimentation per foot of settling distance are not over 0.5 micron in diameter.

The method most commonly used in laboratories consists in settling dust in a tall, narrow vessel such as a graduate. This method has several disadvantages. First, it is difficult to decant a suspension from such a container without disturbing the sediment. Second, the settling distance is so great that small particles require extremely long periods to settle out. Third, if layers of the suspension are recovered by decantation or siphoning, eddy currents are created which upset the separation. This method may be used advantageously for the removal of very large particles from a dust, however, by allowing a suspension to settle only a few seconds, and then decanting the supernatant suspension into another container. The sediment will consist of the large particles which settled out very rapidly.

The use of liquids of high viscosity for the settling fluid has the great objection that these liquids must later be removed, and this process is generally long and troublesome. Only a very slight advantage is to be gained from settling in a liquid of a different specific gravity from that of water. If the specific gravity of the fluid is less than that of water, the settling time for a given size of dust will be shorter than in water, but only by a small amount. So few liquids of higher specific gravity than water are practical that this case hardly needs discussion.

From a consideration of these methods and their disadvantages, the following points are to be observed in obtaining the best results by the sedimentation process: First, the dust

should be uniformly dispersed in the fluid in which it is suspended, and conditions should be such that the particles do not tend to form aggregates. Second, recovery of the sediments yields better results than recovery of layers of the suspension. Third, the choice of the suspending fluid should be based upon a consideration of the range of particle sizes desired. Fourth, the container should preferably be broad and shallow. Fifth, the process should be carried out in a room relatively free from temperature changes and vibrations in order to eliminate interference with the suspension by convection and eddy currents.

In settling dusts ranging between 0.5 micron and 50 microns in size, a water-alcohol mixture has been used as the suspending fluid. The addition of the alcohol to the water serves two purposes: First, it wets the particles very readily, thus aiding in dispersing the clumps of smaller particles which tend to settle as one large particle. Second, because of the lowered surface tension, the sediments adhere firmly to the bottom of the container and there is little or no contamination of the supernatant suspension incident to decantation.

Broad, flat dishes are used which are kept on a level table in the center of the room. This procedure has proved to be satisfactory if the dishes are covered with a glass plate.

Suspensions may be made of any desired concentration up to about 2 per cent. Heavier suspensions than these are not practical owing to the difficulty in obtaining a uniform dispersion of the dust, and also to the fact that hindered settling takes place.

Experimental Procedure

The dust to be separated is thoroughly dried in the drying oven and is then passed through screens suitable for separating particles larger than the upper limit of the size desired. Dust passing through a 270-mesh screen has been used for the separations illustrated.

Twenty-five grams of this screened material are spread evenly over the bottom of a large, flat, glass culture dish 22 cm. in diameter and 8 cm. deep. Dilute 125 c.c. of 95 per cent. alcohol to 250 c.c. and pour this mixture slowly into the dish, and at the same time work the dust to a smooth paste with a rubber "policeman." Add to this suspension a liter of water, stir constantly, and continue the agitation until a homogenous suspension is obtained.

Just as the agitation is stopped, the time is observed and the dust is allowed to settle for one-half minute. The supernatant suspension is carefully but quickly decanted into a second container of the same size. The time is noted at the end of the decantation, and this suspension is now allowed to settle for one minute. The supernatant fluid is decanted as before into a third container, where it is allowed to settle for two minutes. This process is continued, using twice the length of time for each succeeding sedimentation until after the eighth, or sixty-four-minute, sedimentation. It is then decanted into a dish in which it is allowed to settle for twenty-four hours. From this, it is decanted into another dish and allowed to settle for two days, and finally into a dish in which it settles for four days. The

dust is roughly classified by this first process; the largest particles are found in the sediment of the first container, and the finest in the last. Dust remaining in suspension after four days of settling is in such violent brownian movement that it will remain suspended practically indefinitely.

In order to clean these fractions, the "fines" must be removed by further washings. Therefore the sediment in the first dish is again brought into suspension in a liter of the water-alcohol mixture by rapid agitation, and is allowed to settle again for one-half minute. The supernatant suspension, which contains a mixture of "fines," is decanted as before into the dish containing the sediment which settled out in one minute in the first classification. All the dust in this dish is then brought into suspension, allowed to settle for one minute, and then decanted into the following dish. This process is continued through the series and the whole operation repeated as often as is necessary to obtain a clear, supernatant fluid in the settling interval. Beginning with the third sedimentation, water is used rather than the water-alcohol mixture.

When the supernatant fluid is clear at the end of a washing, it is discarded, and the sediment is carefully transferred to a watch glass with the aid of a rubber "policeman." The sediment is then dried in the oven and finally transferred to glass-stoppered weighing bottles.

Throughout the process it is advisable to check the thoroughness of the separation with the microscope. If, after the supernatant fluids are clear, there is still considerable variation in the size of the particles, it is advisable again to divide each sediment into two parts. The sediment which completely settles in four minutes is brought into suspension again and allowed to settle for half its usual settling time, or two minutes, and then the supernatant fluid is decanted into a clean container. Both of these fractions are then settled separately for the original time interval of four minutes. This division may be repeated on each fraction until the dust falls within the desired limits. No specific information can be given for the number of washings necessary to secure clean separations, inasmuch as every sample of dust will contain varying proportions of "fines." Three to five washings, however, are usually sufficient for excellent results.

If a dust of some one particular size is sought, the time of settling is determined by Stokes' law as shown in this paper. Several separations of short intervals are then made, such as one-half, one, two, and four minutes. This frees the suspension of the coarse particles. The suspension is now settled for a period of just one-half the time interval calculated. It is then decanted into another dish in which it settles for the calculated time interval. The sediment in this last dish contains the particles desired, together with many finer particles. These "fines" are now removed by washing the sediment as described.

Observations

The illustrations shown in Figures 1 and 2 are photomicrographs of quartz particles which were separated

by this procedure. This quartz yielded upon analysis:

	%
SiO_2	99.34
Fe_2O_3	0.70
Al_2O_3	

The specific gravity of the dust was determined with a pyknometer as 2.648. The finely ground material was passed through a 270-mesh screen and then separated by sedimentation. The sediments were each washed three times and then each fraction was subdivided into two fractions and settled in another washing for the full time interval.

The particles from each separation were then measured with a calibrated ocular micrometer. Fifty particles in each smear were taken for measurement in the order they appeared in the field. The longest diameter of each particle was measured first, and then the diameter normal to this at its mid-point. The averages of these readings appear in the second and third columns of Table 1.

The diameters of small spheres settling through a fluid of known viscosity at a given velocity may be calculated by Stokes' law. The diameter of the largest particle which may be expected to settle according to Stokes' law is discussed on page 255.

Since the particles settle 3.5 cm. in the various time intervals, the velocities of settling are obtained by dividing the settling distance in centimeters by the time of settling in seconds. These velocities are given in Table 2.

The diameter of a given particle is now obtained by inserting these velocities in Stokes' law:

$$D = \sqrt{\frac{18\mu V}{(S - s)g}}$$

TABLE 1.—OBSERVED DIAMETERS OF QUARTZ PARTICLES SETTLED IN WATER

SETTLING TIME	DIAMETER		
	Longest	Normal to Longest	Average
min.	*microns*	*microns*	*microns*
½	53.4	37.2	45.3
1	39.6	28.5	34.0
2	29.1	21.2	25.2
4	19.9	13.5	16.7
8	14.4	9.7	12.1
16	10.4	7.3	8.8
32	7.5	5.1	6.3
64	4.6	3.7	4.2
days			
1 2 4	....[1]	....	....

[1] No measurement of these particles could be made with the apparatus at hand.

where D = the diameter of the particle in centimeters
μ = the absolute viscosity of the suspending fluid
V = the velocity of settling in centimeters per second
S = the specific gravity of the particle
s = the specific gravity of the suspending fluid
g = the gravity constant

The values to be used in this formula under the conditions outlined are as follows:

μ = 0.0122 at 20°C.
V = values from Table 2
S = 2.648
s = 0.987
g = 980

Diameters calculated from the foregoing data are given in Table 3. Table 4 shows a comparison of these calculated values with the diameters

FIG. 1.—Quartz particles separated into graded sizes × 450.
A—Settling time, 30 seconds; average diameter, 45 microns.
B—Settling time, 2 minutes; average diameter, 26 microns.
C—Settling time, 8 minutes; average diameter, 12 microns.

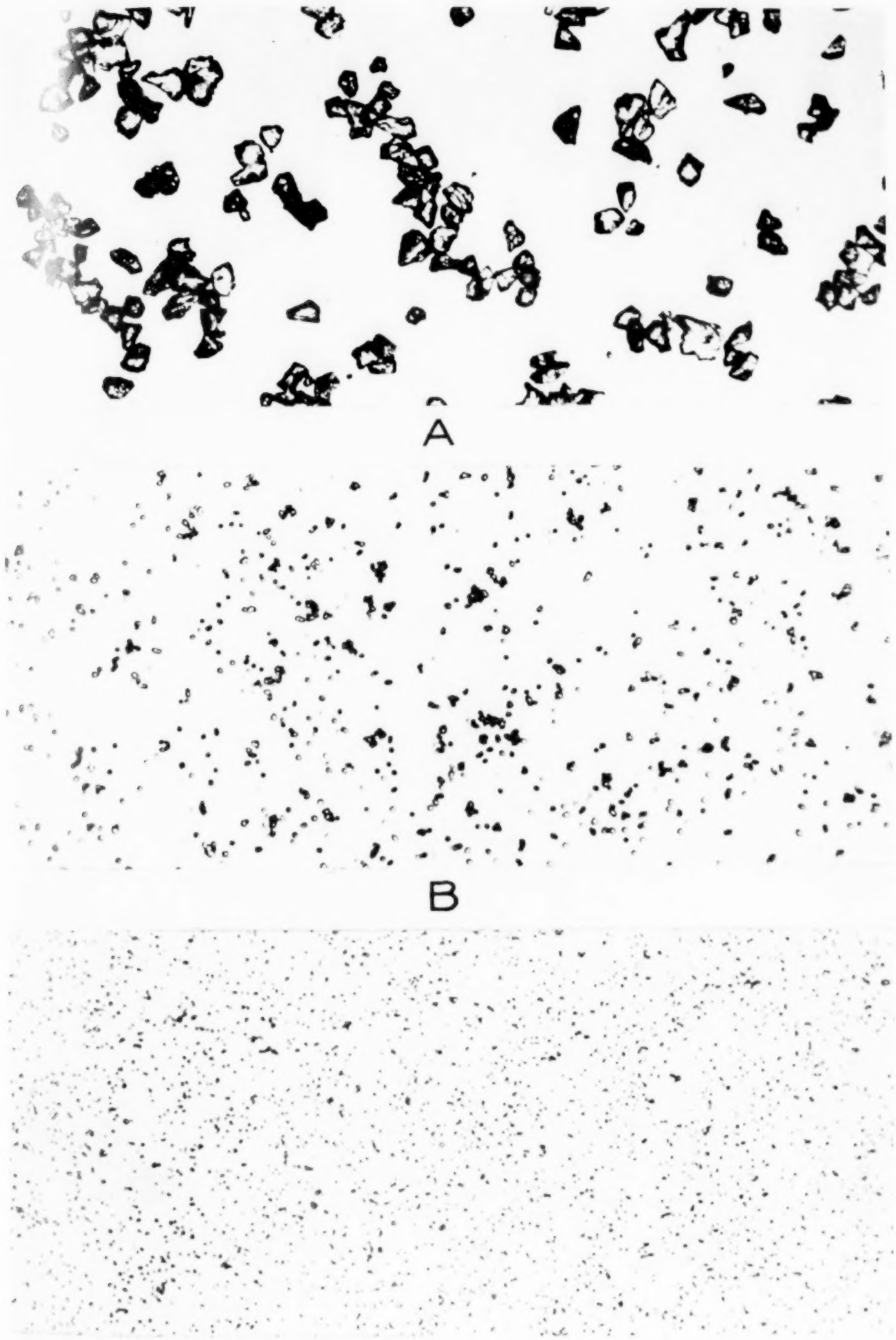

FIG. 2.—Quartz particles separated into graded sizes × 450.
A—Settling time, 32 minutes; average diameter, 6 microns.
B—Settling time, 1 day; average diameter, 1 micron.
C—Settling time, 4 days; average diameter, 5 microns.

of the measured particles. The average factor for the eight observations is 1.22.

TABLE 2.—CALCULATED VELOCITIES FOR QUARTZ PARTICLES SETTLING IN WATER

SETTLING TIME	VELOCITY
sec.	*cm./sec.*
30	0.117
60	0.0584
120	0.0292
240	0.0146
480	0.0073
960	0.00365
1,920	0.00182
3,840	0.000912
86,400	0.0000405
172,800	0.0000202
345,600	0.0000101

TABLE 3.—CALCULATED DIAMETERS OF QUARTZ PARTICLES SETTLED IN WATER

SETTLING TIME	DIAMETER
min.	*microns*
½	39.70
1	28.00
2	19.80
4	14.00
8	9.90
16	7.00
32	4.95
64	3.50
days	
1	0.74
2	0.52
4	0.37

We may now apply this factor to the law in order to derive the particle sizes to be obtained by settling for various lengths of time, or to obtain settling times for various particle sizes when using this procedure.

TABLE 4.—COMPARISON OF OBSERVED AND CALCULATED DIAMETERS

SETTLING TIME	DIAMETER		RATIO OF CALCULATED TO OBSERVED DIAMETER
	Calculated	Observed	
min.	*microns*	*microns*	
½	39.70	45.3	1.14
1	28.00	34.0	1.21
2	19.80	25.2	1.27
4	14.00	16.7	1.19
8	9.90	12.1	1.22
16	7.00	8.8	1.26
32	4.95	6.3	1.27
64	3.50	4.2	1.20
days			
1	0.74	....	....
2	0.52	....	....
4	0.37	....	....

TABLE 5.—VELOCITIES FOR QUARTZ PARTICLES OF DIFFERENT SIZES SETTLING IN WATER

DIAMETER	VELOCITY
microns	*cm./sec.*
200	0.2
100	0.5
50	0.125
40	0.080
30	0.045
20	0.020
10	0.005
5	0.0013
2	0.0002
1	0.00005
0.5	0.000013

For quartz:

$$D = 1.22 \times 0.0116\sqrt{V} = 0.0142\sqrt{V}$$

$$V = 5{,}000\, D^2$$

where V = the velocity of settling in centimeters per second

D = the diameter in centimeters

The velocities for settling quartz particles in water as determined by this formula are given in Table 5.

The time of settling is then determined from the formula:

$$t = \frac{\text{Settling Distance}}{\text{Velocity}}$$

In this case the settling distance is 3.5 cm. and the velocities are those shown in Table 5. The values for t thus obtained are shown in Table 6.

TABLE 6.—SETTLING TIMES OF QUARTZ PARTICLES SUSPENDED IN WATER

DIAMETER	SETTLING TIME
microns	*sec.*
200	1.75
100	7
50	28
40	44
30	78
20	175
10	700
5	2,800
2	17,500
1	70,000
0.5	280,000

A chart such as the one shown in Figure 3 may be readily constructed to determine the time of settling of various particles within the limits of the method.

Discussion

The method described provides separations which are uniform in size. The limits of the individual separations may be made as narrow as desired by repeatedly separating the original fractions. The freedom of the sediments from small particles depends upon the number of times they have been washed. Though it has been shown that quartz particles greater than 400 microns can be separated by Stokes' law, it is not practical to employ this method near its upper limit. For shallow dishes the time of settling is too short; for deeper dishes the volume of fluid handled is too large. The method finds its best application in the range of particles below 50 microns. Particles larger than this may be separated by screening, but for those of smaller size screens are not available. The lower limit is determined by the size of the particle which fails to settle, but remains in suspension owing to brownian movement and owing to the charge on the particles. This limit is about 0.5 micron and is independent of the type of dust settled and corresponds to an actual settling time of slightly over three days by this procedure.

Table 1 demonstrates how clean cut the various separations may be made. It will be seen that the longest diameters of the particles in any settled fraction approximate the shortest diameters of those in the preceding sediment with little overlapping of size. The poorest differentiation is between the thirty-two-minute and the sixty-four-minute sediments, where the deviation from the longest diameter is about 9 per cent.

Table 1 also demonstrates the limits within which a given separation may be made to fall. The average of the longest diameters deviates from the average diameter by a nearly constant figure. The maximum deviation occurs at the four-minute and thirty-two-minute fractions, and is about 19 per cent. The average deviation is 17 per cent.

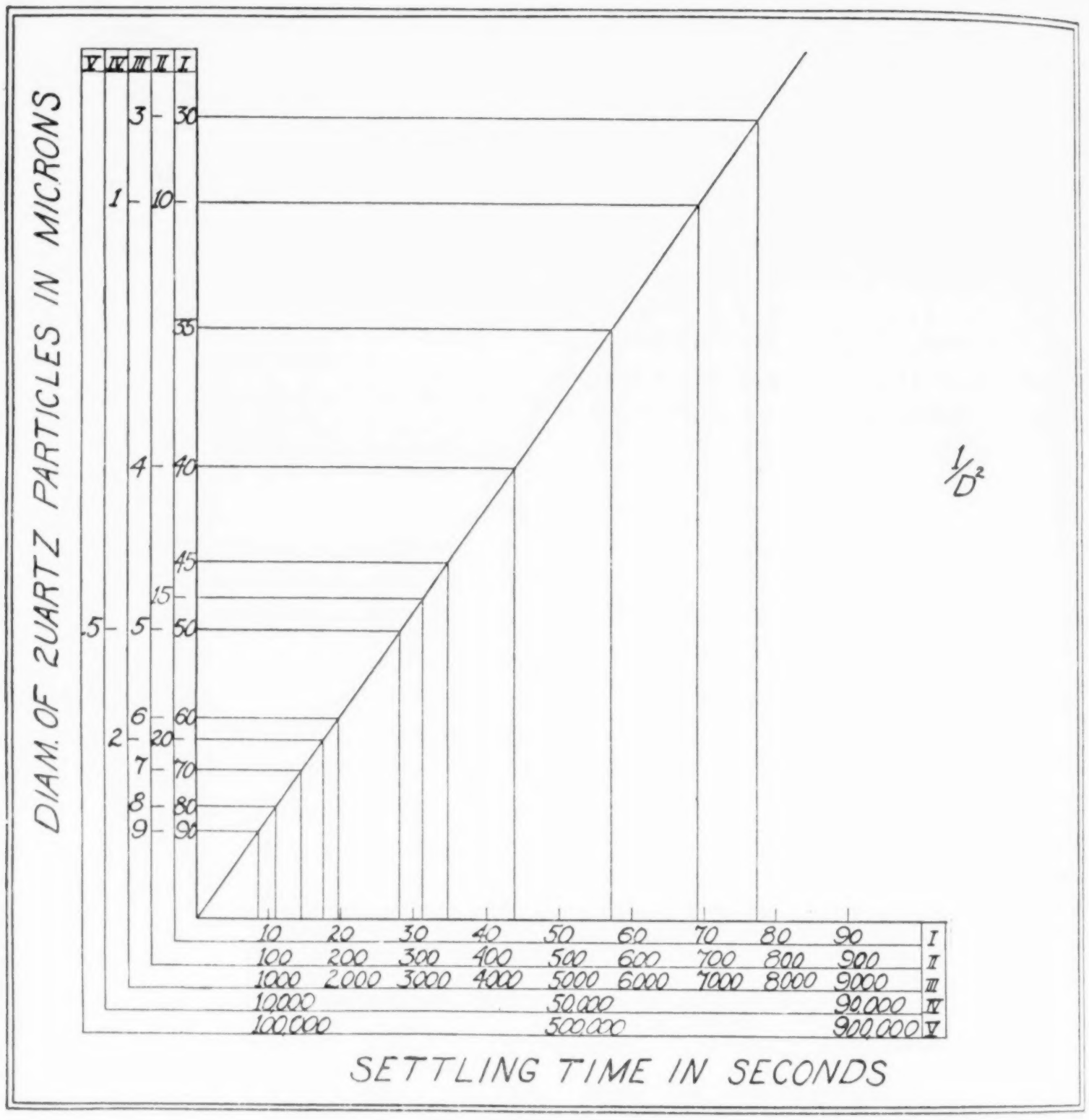

FIG. 3.—Chart for determining time of settling of various particles.

To use the chart: Find the diameter of the particle sought in the ordinates; note the number of the column it is in; run horizontally from that point to the index line and drop vertically from this point to the horizontal column having the same number below. Here will be obtained the time of settling in seconds.

The fact that the observed diameters are consistently larger than their calculated values is largely due to an error in the method of arriving at the diameter of the particle, and to the assumption that the particle is spherical. A more accurate method of obtaining this value would be to measure the true area of each particle; but inasmuch as the particles settle so as to offer the greatest possible resistance to the suspending fluid, they will present their largest cross section when measured. Many of the particles are more nearly flat plates than spheres, and consequently they settle with a velocity different from that of a sphere of equal cross section. The factor of deviation from Stokes' law obtained for quartz could not be

applied to dust particles which have fractured to shapes differing from those illustrated. There is also a tendency for the velocity of settling to be decreased owing to disturbances in the suspending fluid incident to decantation, and owing to hindered settling in heavy suspensions.

A chart has been included from which may be found the settling time in seconds of quartz particles of various diameters expressed in microns. This chart has been made by plotting the time in seconds as abscissas, and the reciprocal of the square of the diameter in microns as ordinates. The quantities derived from the chart are not the theoretical values as calculated from Stokes' law, but represent the values to be expected when this procedure is used. The chart is of no value unless the conditions of the procedure are rigidly adhered to throughout the separation.

Derivation of Diameter of Largest Quartz Particle Which May Be Assumed to Settle According to Stokes' Law

If we assume the particles to be spheres settling in the water-alcohol mixture described, the type of settling can be determined as follows.

The force of gravity acting downward on the particle is:

$$F_g = \frac{\pi D^3 S}{6}$$

(c.g.s. units)

where S = the specific gravity of the particle
D = the diameter of the particle in centimeters

The particle is also buoyed up by a force equal to the weight of the fluid displaced, or:

$$F_b = \frac{\pi D^3 s}{6}$$

where s = the specific gravity of the suspending fluid

The resultant downward pressure is therefore the difference, or:

$$F_g - F_b = \frac{\pi D^3 (S - s)}{6} = F_r$$

If the motion of the particles is fairly rapid, it sets the fluid about it in motion and creates a dynamic pressure opposing the motion of the particle; for a sphere this force has been shown by Lamb (2) to be:

$$F_o = \frac{\pi D^2 V^2 s}{16g}$$

where V = the velocity of settling in centimeters per second
g = the gravity constant

The particle soon comes to a velocity such that F_o and F_r are in equilibrium when:

$$F_o = F_r \text{ or } \frac{\pi D^2 V^2 s}{16g} = \frac{\pi D^3 (S - s)}{6}$$

Solving for V:

$$V_1 = 1.63 \sqrt{\frac{D(S - s)g}{s}}$$

For very small spheres, however, the velocity of settling is so small that the eddying motion is lost and the viscosity of the fluid becomes an important factor. According to Stokes' law (3),

$$V_2 = \frac{D^2 (S - s)g}{18\mu}$$

where μ = the absolute viscosity of the suspending fluid

At a certain particle size, these velocities will become equal, or:

$$V_1 = V_2 \text{ or } 1.63\sqrt{\frac{D(S-s)g}{s}} = \frac{D^2(S-s)g}{18\mu}$$

Solving for D:

$$D = 9.51\sqrt[3]{\frac{\mu^2}{(S-s)gs}}$$

since $\mu = 0.0122$ at 20°C.
$S = 2.648$
$s = 0.987$
$g = 980$

For quartz dust:

$D = 0.0430$ cm.
or 430 microns

Hence Stokes' law may be applied to settling quartz particles as large as 430 microns, or those passing through a 40-mesh screen. The lower limit is determined by the degree of the brownian movement and for quartz in water it is nearly 0.5 micron.

Summary

1. A technic of sedimentation is given by which dusts below 50 microns may be separated into graded sizes.

2. The theoretical limits of the method are discussed.

3. A chart is given for the determination of the settling times for quartz particles of different sizes.

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